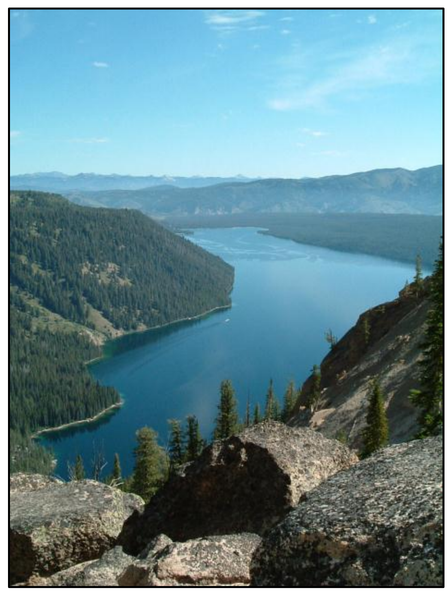
Aquatic Ecosystems & Management

Chapter Goals:
After completing this chapter, volunteers should be able to:

- Describe the characteristics of water
- Communicate the characteristics and properties of aquatic systems
- Understand and communicate how aquatic systems function
- Become familiar with management techniques for aquatic systems
- Understand and communicate threats to aquatic systems

Introduction

Idaho's aquatic ecosystems are as diverse, interesting, and unique as any in the world. Idaho's lakes, rivers, streams and wetlands reflect the diversity of climate and landscapes found in the state. These ecosystems include huge, deep cold-water lakes, small high mountain lakes, large alkaline lakes, streams and rivers of with diverse size, gradient and temperature regimes and wetlands that include vast marshes and diminutive beaver ponds.



Redfish Lake in the central Idaho Sawtooth Range. Photo courtesy, Rex Sallabanks, IDFG

Notably, no "aquatic" ecosystem operates independent of the surrounding landscape. Aquatic and terrestrial ecosystems operate as one system that can best be defined, described and studied as a watershed. Land and water exchange energy (nutrients). As in all systems the sun is the primary source of energy as it is captured by plants to create the foundation for food webs and energy (nutrient) cycles.

Life on earth evolved in an aquatic system. Aquatic systems are extremely diverse ranging from marine (though not in Idaho) to freshwater, static to flowing. While all aquatic systems are dependent on water, not all have a constant water level or continuous water supply. Water, probably more than any other element or compound, makes life possible on Earth. In this chapter we will explore the properties of water, aquatic ecology and management of aquatic systems.

Characteristics of Water

Water's unique properties "explain" why water is the basis of life and why aquatic systems function as they do. Water's simple structure of 2 hydrogen atoms and 1 oxygen atom is the basis for water's unique properties. These properties include surface tension, specific heat, and ability to dissolve other substances. Also important is that water at moderate earth temperatures is in a liquid state, and so it forms our oceans, rivers, wetlands, and lakes.

Water is an extremely stable compound, meaning it does not breakdown or interact in chemical reactions readily. The H2O formula for water indicates that each water molecule consists of two atoms of hydrogen and one atom of oxygen. However, water has a most interesting and unique structure, in that the hydrogen atoms do not oppose each other at a 180◦ angle to the oxygen but instead cluster to one side, at 104.5◦ angle to the oxygen atom. This angle gives the water molecule a "bipolar" structure with the hydrogen side being positively charged and the oxygen side being negatively charged. These unequal charges make the water molecules attract each other, forming clusters with each water molecule bonding to three others (forming what is called a "tetrahedral" structure of 4 water molecules). This structure gives water the unique abilities to:

- develop surface tension,
- be a solid, liquid, or gas over a relatively small temperature range,
- become less dense in its solid state (ice floats),
- have a high specific heat, and
- dissolve other substances.

The surface tension of water gives its strong, elastic exterior. It is because of surface tension that water forms droplets, moves through minute openings in soils and living tissues, and allows some creatures to inhabit its surface.

The bonds water forms with surrounding water molecules and other molecules are called "hydrogen bonds." These weak hydrogen bonds between water molecules are constantly breaking and reforming depending on temperature and pressure. As temperature increases (and pressure decreases) this molecular activity increases and some water molecules are lost from the surface of the water to become "water vapor" (water vapor are single molecules of water).

As water vapor cools, it re-forms or condenses to liquid water (i.e. forms clouds). *A unique property of water is that its solid state is less dense than its liquid state.* As liquid water cools, its structure becomes most dense at 4 degrees C or 39 degrees F. Because of its tetrahedral structure, water cooled below this temperature becomes less dense, traps more gasses, and therefore freezes or becomes a solid at the surface, not as a block. This is biologically important because it causes the mixing and turnover in lakes. The surface ice traps warmer water (usually 39 degrees

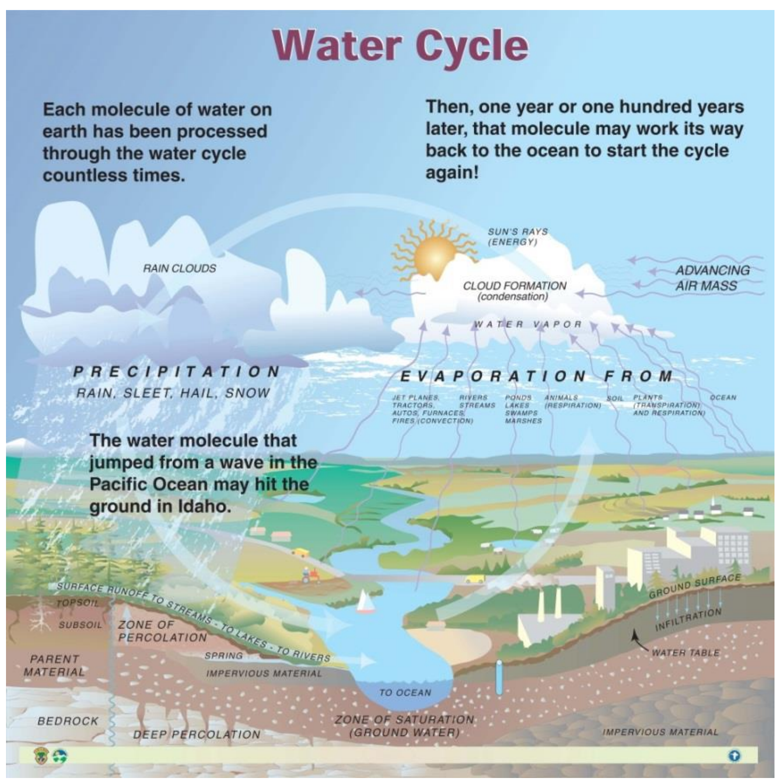
F) below and makes it difficult for large bodies of water to freeze solid. The fact that water freezes at the surface but not uniformly (as a solid block) makes life possible under the water during cold times.

A substance's specific heat is its capacity to absorb heat or thermal energy in relation to temperature at a constant volume. Water has an extremely high specific heat, which means it absorbs or releases heat slowly and therefore stores large quantities of thermal energy. This allows all bodies of water (particularly oceans) to store enormous amounts of energy in the form of heat. This stored energy is then transferred to the atmosphere and drives global weather patterns. This specific heat of means even small water bodies warm and cool slowly compared to the atmosphere, making aquatic systems very stable environments for aquatic organisms.

Finally, water is considered the "universal solvent" because of its ability to dissolve so many other elements and compounds. Substances dissolved in water (minerals, nutrients, gasses, etc.) then move freely, or diffuse, within the water body, making them available to aquatic organisms. These physical characteristics of water make it the medium of life on Earth and life as we know it cannot exist without water. Most plants and animals are comprised primarily of water. The human body is 75% water!

The Water Cycle

The water or "hydrologic" cycle is basic to life on the earth. It is a continuous process involving the exchange or circulation of water between the oceans, the atmosphere, and the land. The energy forces that drive the hydrologic cycle are solar radiation and gravity. It is estimated that 1.1 X 1015 acre-ft. or 325,550,833 cubic miles of water exist on the earth. Over 97% of this water is in the oceans with the remainder in ice (glaciers, snow, etc.) 2%, groundwater 0.58%, lakes and rivers 0.02%, or the atmosphere 0.001%. The amount of fresh water is only 2.29 X 1013 acre-ft. Living organisms utilize only 0.000078% of the total water on the earth.



To put this into perspective, if a five gallon bucket of water represented all the water on the earth, only 1 tablespoon of that water would represent the amount living organisms utilize. Evaporation (mostly from the oceans) and transpiration (from plants) releases water vapor to the atmosphere. Atmospheric water falls back to the earth as rain or snow precipitation. Water falling as precipitation can:

- evaporate back into the atmosphere,
- collect to form fresh surface waters (rivers, lakes, etc.),
- percolate into the ground, or
- be incorporated into living organisms.

Fresh surface waters can evaporate into the atmosphere, percolate into the ground, be absorbed by organisms, or flow back to the oceans. Ground water can flow back to surface water, be absorbed by plants, be stored in “aquifers,” or flow back to the ocean. It is estimated that the recycling or renewal times for water are:

- 37,000 years for oceans,
- 16,000 years for ice,
- 300 years for groundwater,
- 1-100 years for lakes,
- 280 days for soil moisture,
- 12-20 days for rivers, and
- 9 days for atmospheric moisture.

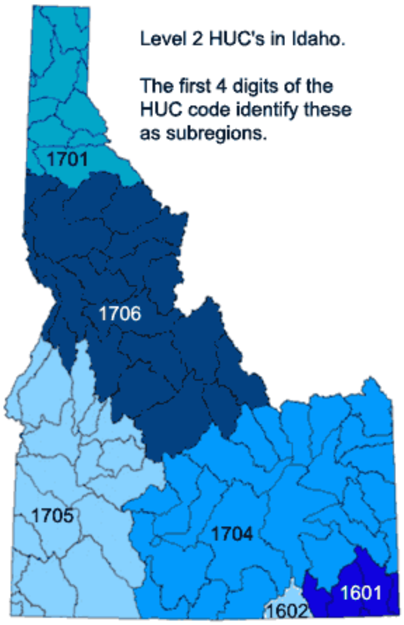
Thus, freshwater is very transient and rapidly recycles.

Characterizing Aquatic Systems

Aquatic systems can be divided into “lentic” or "lotic” systems. Lentic systems are standing or non-flowing waters while lotic systems are flowing water systems. Obviously, this classification is overly simplistic and both systems have many common characteristics as well as some distinct differences. Wetlands, reservoirs, and aquifers are examples of aquatic systems that have both lentic and lotic characteristics.

Watersheds

A watershed is the land area from which water drains into a common watercourse. All land is part of a watershed and we all live within a watershed. As water moves along the surface, through the soil, or through rock layers it dissolves and transports sediment and minerals.

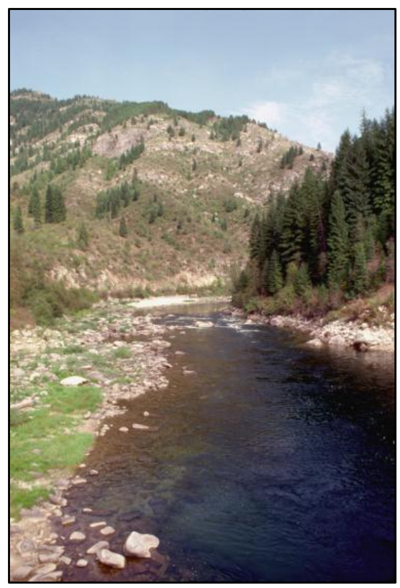


H.U.C. is an acronym for Hydrologic Unit Codes. Hydrologic unit codes are a way of identifying all of the drainage basins in the United States in a nested arrangement from largest (Regions) to smallest (Cataloging Units). A drainage basin is an area or region of land that catches precipitation that falls within that area, and funnels it to a particular creek, stream, and river and so on, until the water drains into an ocean. A drainage divide is the division between adjacent drainage basins. Just as a creek or stream drains into a larger river, a drainage basin is nearly always part of a larger drainage basin. Drainage basins come in all shapes and sizes, with some only covering an area of a few acres while others are thousands of square miles across. Drainage basins cross artificial boundaries such as county, state, and international borders. The term watershed is often used in place of drainage basin.

Digital Atlas of Idaho http://imnh.isu.edu/digitalatlas/hydr/huc/huc.htm

Lotic systems

Streams, creeks, and rivers are lotic systems (moving water environments). Streams in a watershed are classified based on size and hierarchy in the watershed. The smallest streams in a watershed have not tributaries or feeder streams and are classified as “first order streams.” First order streams run together forming “second order streams,” and second order streams run together to form a “third order stream” and so forth up to “tenth order streams.” First, second, and third order streams are called “head-water” streams. Fourth, fifth and sixth order streams are called mid-sized streams and seventh through tenth order streams are large streams or rivers.



A river is an example of a lotic system. Photo courtesy, IDFG.

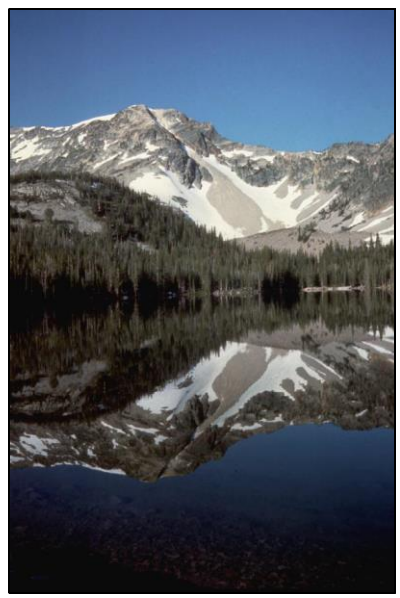
Streams in upland areas generally have higher gradients/slopes and are cooler and faster-flowing than streams in lowland areas. Rainfall, stream gradient, vegetation, and soil/substrate generally determine stream flow characteristics. Streams that flow constantly are called “perennial streams” while those that flow only occasionally are called “intermittent streams.” Many first and second order streams are intermittent.

Flow rate or velocity varies widely within a stream or lotic system. Streams are usually characterized by pools, riffles, and meanders (bends). Pools are deeper, slower moving water sections while riffles are shallow, faster moving water sections of a stream. Meanders change the flow patterns of streams by focusing currents into specific areas and thus creating pools or rifles. Rainfall in the watershed increased flow in the streams. High flow velocities scour streambeds, moving stones, gravel, and silt, and cutting new channels and banks. Flowing waters transport nutrients, sediments, and aquatic organisms. Aquatic organisms that live in these lotic environments must adapt to withstand these flow changes, find sheltered areas, or be transported downstream.

The primary energy source in lotic environments is exogenous (from the outside). Organic material and nutrients from the surrounding environment or watershed supply energy for bacteria and other micro-organisms, macro-invertebrates, and fish. Some photosynthetic production does occur from algae and rooted vegetation, but is minor compared to the influx of organic matter from the outside.

Lentic systems

Lakes, ponds, and ephemeral pools are lentic systems (still water). However, all are part of a watershed and receive water from rainfall events. Most lakes and ponds overflow during heavy rainfall and thus have some characteristics similar to lotic systems. Ponds and lakes accumulate exogenous nutrients and sediment over time, becoming nutrient rich and shallower with less volume. This accumulation and its associated changes are part of the natural successional cycle. Lakes tend to accumulate sediments near the shoreline and thus slowly become shallower and smaller in volume from the edges inward. The expected life of a pond is only from 25-100 years before it is filled in to the point it becomes a swamp or wetland. Watershed characteristics above the pond or lake will determine the life of the water body. These characteristics include soil type, slope, vegetation type, and land use patterns. Agriculture practices like row-cropping and excessive livestock grazing, mining and certain industrial practices in the immediate watershed increase nutrients and sediment accumulation in ponds and streams.



The high mountain lake is an example of a lentic system. Photo courtesy, IDFG.

Light penetration drives lentic systems probably more than any other single factor. The littoral zone and limnetic zones of a lentic system are where light penetrates. Only in these areas can plant grow or photosynthesize. Turbidity in the water also affects the depth of these zones. In the littoral zone light penetrates to the bottom and this region tends to be highly diverse and productive in plant and animal life. While exogenous materials dominate the food chain of lotic systems, lentic systems produce most of their own food (endogenous) through photosynthesis of plants within the system.

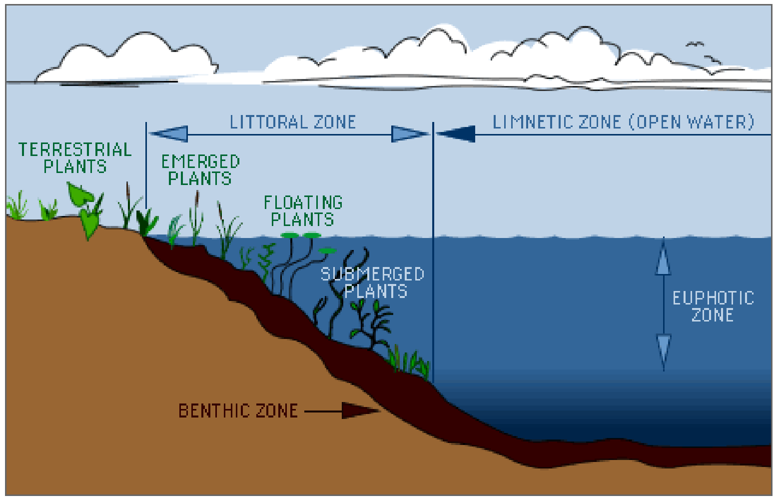


Diagram of lake zones courtesy of Water on the Web, University of Minnesota.

The limnetic zone is open water where light penetrates. Free-floating and microscopic plants (phytoplankton), microscopic animals (zooplankton), and pelagic (open water, away from the shore) animals inhabit this zone.

Light does not penetrate into the profundal zone below the limnetic zone. This zone can be inhabited by animal life, but is dependent on temperature, dissolved oxygen, and other water quality factors. This zone can become anaerobic (depleted of oxygen) at times and may be inhabitable by life forms other than anaerobic microorganisms (e.g. bacteria).

The benthic zone is the bottom and consists of organic and mineral sediments. Much of the benthic zone can be anaerobic, particularly below the profundal zone. However, where oxygen is present, this zone is highly productive and inhabited by invertebrates that consume detritus (decaying material).

Water and Temperature Quality Parameters

Temperature, driven by solar energy, is the primary physical parameter in aquatic environments. Most aquatic organisms are poikilothermic or "cold-blooded" meaning that they assume the temperature of their environment. This means environmental temperature affects their metabolism and controls feeding, reproduction, and behavior. Many microorganisms survive and thrive only over specific temperature ranges and are dormant outside that temperature range. Even fish are often

This cutthroat trout needs cold water to survive. Photo courtesy, Chris Schnepf, University of Idaho, Bugwood.org classified as cold, cool, or warm water species. Trout for example are cold-water fish and cannot survive at temperatures above 20◦ C or 68◦ F, while many warm-water species cannot survive temperatures below 13◦ C or 55◦ F. Temperature differences are ecologically very important and determine species composition, food chain diversity, and nutrient recycling. Shallow water changes temperature more rapidly than deep water and water surfaces exposed to sunlight warm faster and stay warmer than shaded waters (i.e. streams with tree canopies). In general, water changes temperature slowly (see specific heat section above) enough that it never gets as cold or as warm as the air. As water warms, evaporation tends to release heat and slow the warming effect of solar energy. As water cools, the warmer water sinks and the cooler water rises (at 39 degrees F) and eventually freezes at the surface.

Turbidity

Turbidity is the degree to which water is transparent (its natural color). Suspended sediments, dissolved substances, and micro-organisms decrease water's transparency and thus increase turbidity. Turbidity caused by suspended solids (muddy water) can be an indication of erosion problems within the watershed or a clay layer within the water body's substrate. Lowland streams tend to have turbid water because of the constant influx of sediments after rainfall, especially in disturbed watersheds (logging, fire, grazing), and the redistribution of sediments in the stream itself.

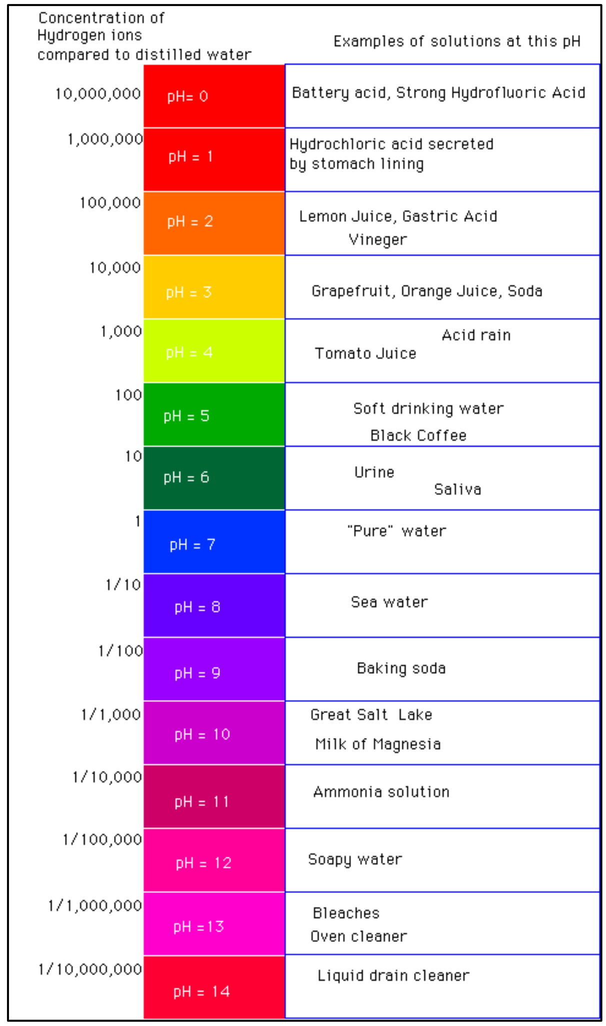
Turbidity can influence temperature of water. Turbid water is darker in color than clear water and thus absorbs more sunlight and heat.

Highland streams tend to be less turbid. Turbidity caused by microorganisms, usually algae, indicates the presence of nutrients. Algal turbidity is an indication of primary productivity, but can also be too dense, indicating high nutrient inflows. Clear water is not necessarily good, as it may indicate low primary productivity or that nutrients are tied up in rooted vegetation and not cycling efficiently through the food chain.

pH

The pH is a scale on which acidity (hydrogen ions) and alkalinity (hydroxide ions) of water is measured. A pH of 7 is neutral (balanced in H and OH ions), above 7 is alkaline (basic) and below 7 is acidic. The pH scale is logarithmic which means that a pH change of 1 point (from a 7 to a 6, for example) is a 10 fold increase or decrease in acidity or alkalinity. Fresh waters generally have pHs between 6-10 (basic). The pH of water is not static and changes or cycles daily. Changes in the pH of a body of water occur during a 24 hour cycle because of respiration and photosynthesis during that period.

Carbon dioxide from respiration (particularly at night) reacts with water to form carbonic acid (releases H^+). Carbonic acid drives pH downward, making the water slightly more acidic. During the day, pH tends to move upward (the water becomes more basic and alkaline) because the carbon dioxide is removed from the water by plants for photosynthesis.



The range of pH for most bodies of water is between 6.5 and 9.5. The pH of water is strongly influenced by the pH of the rocks and soils in the watershed and the accumulation of organic matter in the mud. Water bodies in areas with certain mining activities (e.g. coal) can receive acid drainage causing very low pHs. Often, pH influenced by mine drainage can be in the range of pH 4-6. In areas with thin and acidic soils, acid rain can lower pH in water bodies similar to mine drainage.

The pH of a body of water (i.e. a small pond) can be modified by adding lime, gypsum, alum, bicarbonate, and certain other chemicals as discussed later in this chapter. One might do this if trying to maintain a fishery or other management objective, but would only be effective on a small body of water.

Alkalinity and Hardness

Alkalinity is a measure of bases in water. These bases include hydroxides (OH^-), carbonates (CO_3^{-2}), and bicarbonates (HCO_3^-). Alkalinity is related to, but not the same as pH. Alkaline bases act as buffers to absorb hydrogen ions and resist or stabilize pH changes.

Hardness is a measure of divalent (+2) ions, mostly calcium and magnesium. In chemical tests, both alkalinity and hardness are measured in parts per million (ppm) of calcium carbonate equivalence, which leads many people to believe they are the same. If alkalinity and hardness are both derived from limestone soils, then they usually have similar values. It is possible, however, to have water that is high in alkalinity and low in hardness and vice versa.

Dissolved Oxygen

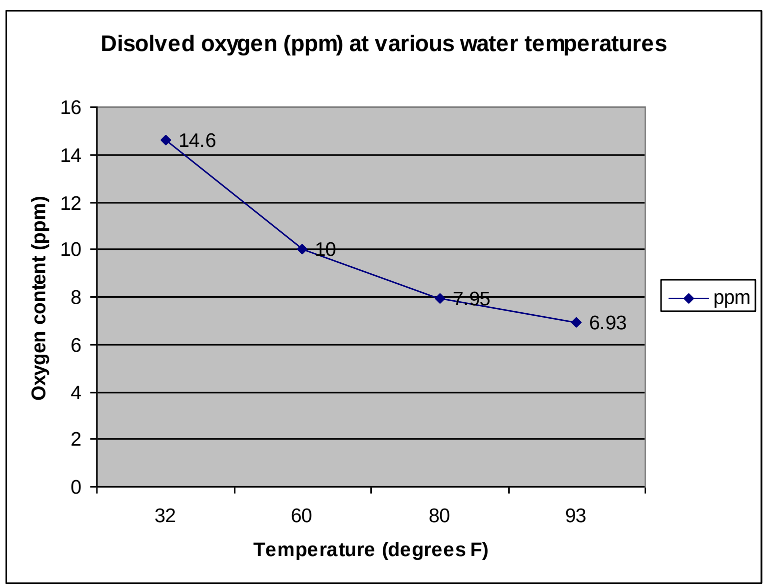
Dissolved Oxygen is probably the single most important water quality factor. Low dissolved oxygen is by far the most common cause of fish kills. Water obtains oxygen from two sources: the air and photosynthesis. Atmospheric oxygen diffuses into water from the air. Diffusion is a slow process but can be aided by the action of wind or some type of agitation that mixes air and water together (e.g. waterfalls, riffles, and aerators).

Oxygen dissolves in water at very low concentrations. Our atmosphere is 20% oxygen or 200,000 ppm. However, seldom will a body of water have more than 10 ppm dissolved oxygen. Oxygen simply does not dissolve well in water. Dissolved oxygen concentrations below 3 ppm stress most warm water species of fish (5 ppm for cold-water species) and concentrations below 2 ppm for prolonged periods will kill many species and large fish. Also many fish that have been stressed by low dissolved oxygen concentrations will become susceptible to diseases.

The primary source of oxygen for lentic (still water) water bodies is from microscopic algae or phytoplankton. Submerged plants also produce oxygen but not in the quantities phytoplankton produce. In the presence of sunlight, algae and submerged plants produce oxygen through photosynthesis and release this oxygen into the water. At night and on very cloudy days, algae remove oxygen from the water for respiration. In lotic or stream environments, oxygen concentrations are more stable because the moving water is constantly dissolving oxygen from the atmosphere.

At night, no oxygen is produced and the respiration of the algae, higher plants, fish, and decomposers (bacteria and other microorganisms) remove oxygen from the water. Thus, dissolved oxygen cycles up and down daily, with photosynthesis and respiration. Under normal conditions, more oxygen is produced by photosynthesis than is removed by respiration.

Cold water holds, or will dissolve more oxygen than warm water. Therefore, as temperature increases, less oxygen will



There is a negative relationship between water temperature and dissolved oxygen. As water temperature decreases, the amount of dissolved oxygen increases. Cold water holds more oxygen.

dissolve. The amount of oxygen that water will dissolve at different temperatures (saturation) and sea level atmospheric pressure varies as is illustrated on the chart on page 10.

Water bodies can supersaturate with oxygen on sunny days when algal populations are dense (heavy bloom). Very high concentrations of oxygen (twice saturation) during the day indicate that oxygen depletion might occur that night.

Critically low dissolved oxygen concentrations can usually be predicted. Low dissolved oxygen levels occur because of one of the following:

- Too many pounds of fish present.
- Extremely high oxygen demands, due to high nighttime respiration caused by dense algal blooms or dense stands of submerged vegetation plus fish waste decomposition.
- Excessive decomposition from algae bloom or aquatic macrophyte die-offs.
- Turn-overs related to weather changes such as rain, wind, and cold air (lotic systems only).
- Reduced oxygen production from photosynthesis due to reduced sunlight from cloud cover, fog or haze.
- Lack of agitation from wind/waves.

Most low-oxygen problems occur during the summer when temperatures are warm, algae blooms or submerged macrophytes are dense and aquatic organisms metabolic rates are high. All of these conditions can cause more oxygen to be removed from the water body at night than is produced during the day. Also, still and overcast days may reduce the amount of dissolved oxygen absorbed by wave action or produced by photosynthesis. This condition may promote oxygen depletion.

Snow accumulation on iced over lakes can prevent the sunlight from reaching aquatic plants. This condition can also cause oxygen depletion and fish kills. This has happened at Henrys Lake in eastern Idaho.

Fish kills from oxygen depletion can range from “partial” to “total.” In a partial kill, the dissolved oxygen concentration gets low enough to suffocate sensitive species and larger fish, but many small fish and hardy species survive. Most oxygen depletions cause partial fish kills. Total fish kills are relatively rare.

Nitrogen Wastes

All animals produce nitrogenous wastes from the digestion and metabolism of proteins in their diet. Ammonia is the principal nitrogen waste product of aquatic animals. It is excreted directly into the water from the gills and kidneys of fish or other aquatic organisms. Ammonia is toxic at high concentrations to most aquatic organisms.

Ammonia is also produced from bacterial decomposition of the proteins from dead animal or plant matter, including algae. Algae, macrophytes, or bacteria quickly absorb ammonia, once it is released into water. Algae and certain bacteria use ammonia as a nutrient for growth and reproduction. Certain aerobic (oxygen-requiring) bacteria use ammonia as a food source in a process called "nitrification."

Nitrification is an important process by which toxic nitrogenous wastes are decomposed. In the process of nitrification, bacteria of the genus Nitrosomonas convert (oxidize) ammonia to nitrite, and bacteria of the genus Nitrobacter convert nitrite to nitrate. Ammonia and nitrite are both toxic to some species of fish; nitrate is not. Ammonia in water dissolves into two compounds: ionized (NH_4^+) ammonia and un-ionized (NH_3) ammonia. Un-ionized ammonia is extremely toxic to fish and most other aquatic organisms, while ionized ammonia is relatively nontoxic. Un-ionized ammonia levels as low as 0.4 ppm can cause death of small fish. Reduced growth and tissue damage can occur at levels as little as 0.06 ppm.

$$\underset{\text{Ammonia}}{NH_4^{+}} \xrightarrow{\substack{\textit{Nitrosomonas} \\ \text{bacteria oxidize}}} \underset{\text{Nitrite}}{NO_2} \xrightarrow{\substack{\textit{Nitrobar} \\ \text{bacteria}}} \underset{\text{Nitrate}}{NO_3^{-}}$$

The ratio of the total ammonia nitrogen (TAN) in the un-ionized form depends on temperature and pH. The amount of toxic un-ionized ammonia increases as temperature and pH increases. Under good water quality conditions, ammonia is seldom a problem. Ammonia can become a serious problem if:

- Overfeeding or over fertilizing is common.
- A sudden algal/phytoplankton or macrophyte die off occurs.
- Excessive amounts of manure from livestock wash in to the water body.
- A high afternoon pH drives the un-ionized ammonia concentration to a toxic level.

High ammonia levels can occur at any time of the year, but they are most likely during the summer because of higher metabolic rates. Managing high ammonia levels is difficult to impossible.

Nitrite is also toxic to some species of fish and other aquatic organisms. Under normal conditions, nitrite does not accumulate to toxic levels because it is rapidly absorbed by algae bacteria, or macrophytes. Nitrite can reach toxic levels if bacterial decomposition (nitrification) is disrupted in small impoundments, especially those with high feeding or manure inputs. Most nitrite problems occur during fall and winter, when sudden changes in water temperatures disrupt normal bacterial decomposition.

Temperature, dissolved oxygen, and chloride ions affect nitrite toxicity. A nitrite concentration as low as 0.5 ppm can cause stress in some species of fish. Nitrite toxicity is reduced in waters with chloride ions in the range of > 30 ppm.

Phosphorous

Phosphorous is an essential element for plant growth. The amount of phosphorous often regulates primary productivity in a body of water. Some phosphorous enters bodies of water in run-off from the watershed and in groundwater from the dissolution of phosphorous in rocks. Phosphorous can exist in several chemical forms, but the soluble orthophosphate is most available to aquatic plants. Concentrations of total phosphorous are usually very low in water bodies and seldom exceed 0.1 ppm. The fate of most phosphorous is to end up in the mud. Phosphorous precipitates or is absorbed by aerobic muds. The rate of this absorption depends on acidity and/or calcium carbonate content. As pH and calcium carbonate concentrations go up, so does the rate of absorption. Some phosphorous re-dissolves into the water but usually is insufficient to maintain algal blooms. Rooted aquatic macrophytes can absorb phosphorous directly from the water or from the mud.

Research has shown that primary productivity can be increased through the addition of phosphate fertilizers. Many private impoundment managers use high phosphorous fertilizers to increase primary productivity and thus fish biomass.

Ecology: How do Aquatic Ecosystems Work?

Aquatic ecosystems work like all other ecosystems-solar energy serves as the ultimate source of energy which is captured and moved through various life forms.

Lentic systems are often classified based on nutrient inputs and cycling. The process of change from nutrient poor to nutrient rich is called eutrophication." Nutrient poor lakes are classified as "oligotrophic." Typically these lakes have low input of nutrients from their watersheds (particularly phosphorous), inorganic sediments, a small surface to volume ratio (i.e. deep), and low productivity. Oligotrophic lakes are generally clear, blue-water lakes with low dissolved oxygen demands, low rates of decomposition, and low total biomass or numbers of organisms. Typically oligotrophic lakes are found in areas dominated by igneous rocks.

As nutrients increase, particularly phosphorous, lakes are classified as mesotrophic. Mesotrophic lakes tend to have moderate inputs of nutrients from their watersheds, some organic buildup in the sediments, and moderate productivity.

As nutrients increase further, lakes become eutrophic. Eutrophic lakes tend to be shallow, have high nutrients, high organic sediments, and green-water lakes. Eutrophic lakes have high dissolved oxygen demands, high rates of decomposition, and high total biomass of aquatic organisms.

An example of a eutrophic lake.
This lake is shallow, with abundant plant life.
Photo courtesy, Mark Moultan,
Sawtooth National Recreation Area

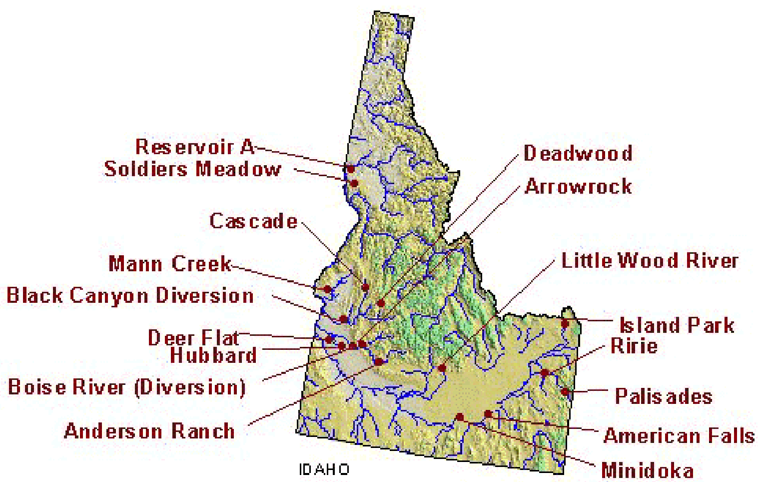
Typically, all lentic systems undergo eutrophication as part of natural succession. Eventually, all reservoirs and ponds fill with sediment becoming wetlands and eventually dry land. The natural process of eutrophication can be accelerated by human activities like mining, farming, urban development, etc.

The moving water of lotic systems strongly influences the characteristic of its ecology. Lotic systems fluctuate widely and rapidly in volume of stream flow and input of nutrients because of substrate and inflow differences. Flooding and drought strongly influence stream flow rates and nutrient inputs as does cultural uses of the watershed. The slope or grade of a stream influences its erosion and siltation characteristics. Streams with steep slopes have high flow rates, are relatively straight with rapids and waterfalls and tend to erode banks and cut deeper channels. As stream slope moderates flow rates are reduced, heavier sediments dropout or are deposited, and the stream forms bends or meanders. Often, these meanders double back on themselves and then get cut-off from the main stream because of flooding and deposition to form “oxbow” lakes. When the stream/river reaches relatively flat slopes, its velocity is greatly reduced, it spreads out and deposits much of its sediment.

Flood events cause the stream to overflow its banks and deposit sediment in the “flood plain.” Because of their deep and nutrient rich soils, people have extensively utilized flood plains for agriculture and settlement. When a stream flows into a lake or the ocean, the remaining sediment drops out forming a fan-shaped “delta.” Most of Idaho’s reservoirs are constructed on stream or river course and therefore trap large amounts of sediments from the upstream watershed. This sediment not only reduces the volume of the reservoir, but also introduces nutrients, which accelerate eutrophication.

The Minidoka Dam near Rupert, ID creates Lake Walcott by damming the Snake River.
Photo courtesy, Bureau of Reclamation

Streams with their constant input of nutrients from the watershed and transportation downstream of these nutrients along with some organisms, particularly during floods, are highly dynamic systems. Stream temperatures tend to be moderate and dissolved oxygen and carbon dioxide concentrations tend to be relatively stable and high, except in very deep pools during low flow or because of pollution. These conditions increase productivity to the point that most streams are 6-30 times more productive than lentic waters.



In Idaho, there are many reservoirs. Most were dammed for water supply, electrical generation, irrigation, or flood control. Dams dramatically alter a river's ecology and hydrology. Reservoirs trap nutrients and sediments that were previously transported downstream and alter flow patterns. Basically, dams replace a lotic system with one more lentic in nature. Most aquatic organisms adapted to lotic environments cannot tolerate static water conditions and are eliminated or severely reduced in reservoirs. Downstream of reservoirs water flows can fluctuate radically from high flows during peak hydroelectric generation, or high releases during flood events, to little or no flow during off-peak hours or drought conditions. These abnormal flow patterns adversely impact many lotic fish and invertebrate species. For this reason, today most reservoirs are operated to provide a minimum stream flow at all times in an effort to provide critical habitat conditions for lotic organisms.

Aquatic Flora

Aquatic flora includes a wide variety of plants from microscopic algae to large trees. Generally aquatic plants are divided into four groups: 1) algae, 2) floating, 3) submerged, and 4) emergent. Algae are primitive plants that do not flower or produce seeds but reproduce asexually or through spore production. All other aquatic plants are angiosperms (flowering plants). Floating aquatic plants are only those that completely float (roots and all) and not those with just floating leaves. Submerged plants have flaccid stems and are usually rooted to the bottom. Emergent or shoreline plants have relatively rigid stems. Most submerged and all emergent plants inhabit only littoral zone (area between high and low water) while planktonic algae and true floating plants and some submerged plants such as hydrilla and milfoil can inhabit the limnetic (lighted surface water) zone.

Some aquatic plants have mechanisms that allow them to transport oxygen from the atmosphere throughout the plant and thus survive in anaerobic water or soil conditions. Many aquatic plants have no cuticle like terrestrial plants and thus can easily absorb gasses and nutrients directly from the water. Many rooted aquatic macrophytes are perennials and have rhizomes, tubers, or stolons, which store food reserves and resprout or root to form new plants. Most floating aquatic plants have waxy surfaces to shed water and keep their stomata open. Often floating and emergent aquatic plants transpire large amounts of water into the atmosphere and can contribute to increased water loss from rivers and reservoirs.

Eurasian water milfoil grown in a fish tank to show people what the plants look like underwater.
Photo courtesy, Robert L. Johnson, Cornell University, Bugwood.org

In small reservoirs and lakes, with their relatively shallow depths and usually high nutrient inputs, native aquatic plants can take over large areas reducing access, and impacting fishing and other activities. However, in large public water bodies it is usually non-native aquatic plants that are problematic. These non-native species were introduced into the environment without any of their native diseases, herbivores, or other controlling factors. Without any natural checks-and-balances, these plants can invade and infest large areas, restricting navigation, recreation, irrigation, and other societal uses. Eurasian water milfoil is a noxious aquatic plant spreading rapidly in Idaho waters.

Aquatic Fauna

Aquatic ecosystems also support a large and diverse group of animals (fauna) ranging from microscopic zooplankton, worms, and fish to reptiles, birds, and mammals. Like aquatic flora, aquatic fauna have special mechanisms to survive in aquatic environments, including mechanisms for reproduction, respiration, movement, food gathering, and many other vital functions. In particular, aquatic animals use more energy to move through the water because of its density than land animals use to move through the atmosphere. Therefore, most aquatic animals are streamlined and have surfaces with reduce friction or repel water (e.g. ducks). Also because of the aquatic environment internal fertilization is unnecessary and most aquatic animals simply release sperm and eggs into the water, where fertilization and incubation occur.

Stream invertebrates often have adaptations for clinging to surface of rocks or vegetation or for burrowing into the sediment. Fish that must swim fast to chase prey or fight strong currents must be more streamlined than fish that inhabit slow-moving or stagnate waters. Mammals and birds inhabit aquatic environments often have webbed feet and specialized organs for capturing prey.

Again, not all aquatic fauna are native. Non-native species problematic in Idaho's waters include brook trout, introduced hatchery rainbow trout, lake trout, walleye, northern pike, and carp. These species often out-compete, replace, or alter the environment of native species.

Aquatic Food Chains and Webs

All food chains, whether aquatic or terrestrial begin with plants. Plants, and a few chemosynthetic bacteria, capture energy for sunlight and manufacture food. A "food chain" is then the transfer of this food energy, starting with plants, through a series of organisms, eating one another. In ecological terms, green plants and chemosynthetic bacteria are called "primary producers." All other life forms are consumers. Consumers are subdivided into groups such as "primary consumers," or "herbivores" meaning they consume only plants directly. "Secondary consumers" or "carnivores" consume animals that consume plants. "Omnivores" consume both plant and animal matter. Parasites consume the tissue of another living creature, usually without killing it. "Detritivores" consume dead or decaying organic matter. Some food webs have a secondary carnivore which consumes other carnivores.

Generally, food chains are no more than four or five sequential steps or links long. The shorter the food chain, or nearer the organism is to the start of it, the greater the amount of energy available. Available energy is converted into biomass or living tissue. Herbivores are closer to the start of the food chain, and therefore, have more available energy and greater biomass as a group than carnivores (the biomass of all the plants is greater than the biomass of all the trout). Animals near the start of the food chain (aquatic examples here) are said to feed "low on the food chain." In general, as one animal consumes another, about 10% of the energy obtained is converted into biomass (tissue) and 90% is lost in metabolism. Food chains are not independent from each other but form an interconnected "food web." Food webs are usually extremely complex involving a multitude of organisms.

In freshwater, all food chains start with algae, chemosynthetic bacteria, or high vascular plants. Algae are by far the most important primary producers in aquatic food chains. Herbivores are generally either free-floating, near microscopic, animals (i.e. zooplankton), insects, crustaceans, mollusks, or worms. Zooplankton, insects and crustaceans are by far the most important primary consumers in aquatic food chains. A few native North American fish are omnivorous but none are strictly herbivorous. In freshwater, the major food chain is detrital based. Little direct herbivory takes place, the major energy pathway is from detritus. The primary consumers of detritus are bacteria and fungi, protozoans, worms (annelids and nematodes), mollusks, insects, crustaceans, and some species of fish.

How do we mimic Natural processes in Aquatic Systems?

First, it is important to remember that most Idaho's rivers and streams have been modified (dammed) for cultural purposes. Cultural purposes can include water supply (human, animal, and irrigation), navigation, hydroelectric power, flood control, pollution abatement, recreation, or fish and wildlife habitat. Most dams, whether public or private, have more than one purpose and management must reflect the desired uses. Therefore, possibly the most important question is what are we managing for?

Watershed Management

First, it should be obvious from the previous discussions that siltation, water quality, and other critical factors are influenced by the watershed, whether a lentic or lotic system. Therefore, any aquatic management strategy must include watershed management. Critical watershed management strategies could include:

- establishing better vegetation cover,
- reducing nutrient inputs,
- reducing livestock and agricultural impacts, or
- creating a riparian buffer.

Often clay turbidity or muddiness is cause by exposed soils in the watershed. Establishing vegetation in the watershed to cover exposed soils can reduce or eliminate clay turbidity and reduce erosion and siltation. Usually native turf grass or other vegetation establishment is the simplest way to reduce erosion in areas with full sun conditions. The size or width of vegetation needed to stop turbidity depends on conditions of watershed size, slope, and rainfall events.

Vegetation buffers around water can help decrease the amount of erosion and water turbidity. Also vegetation around water will reduce the nutrients entering ponds or streams from the watershed.

Again, larger vegetative buffers are needed for greater slopes and larger runoff areas. In general, the larger buffer, the greater nutrient absorption. Nutrients can also be reduced by not applying fertilizers or manures close to ponds or streams. Fertilizers and manures should not be applied within a minimum of 30 feet of ponds and streams.

Livestock trample vegetation around ponds and streams, leading to de-vegetation and erosion. The erosion caused by livestock tends to produce shallow areas and turbidity. Shallow shorelines can encourage the invasion of unwanted aquatic vegetation. Livestock should be fenced from ponds and streams and provided with water troughs that are away from ponds or sensitive riparian areas. Where water troughs are no possible, livestock should be fenced from all but a small section of the pond or stream. The area selected for livestock access should have a gentle slope and be where runoff is limited. Access should not be on a pond dam. Often adding gravel to the access area will reduce livestock impacts.

Riparian buffers are usually associated with rivers or streams. They are simply zones along the borders of streams. They are simply zones along the borders of streams that are left intact with native vegetation adapted to riparian conditions. Again, these act as filters for nutrients, reduce erosion and siltation, and serve as wildlife habitat and migration corridors. A minimum width for a riparian buffer is 50 feet and wider ones are needed in areas of steep slopes or highly erodible soil. Where riparian buffers have been destroyed, native grasses and shrubs can be established to stop erosion and siltation. Over time native woody and herbaceous riparian species may re-establish within the zone.

Management of Rivers and Streams

Most streams, unless intermittent, are considered public waters and therefore cannot be altered without permission of state or national regulatory agencies. However, riparian areas around streams can be managed to entrain nutrients, reduce erosion, and stabilize banks, and encourage wildlife. As previously discussed, maintaining a riparian buffer of at least 50 feet wide and encouraging native riparian vegetation are good management practices along stream corridors.

There are methods to assess stream quality by analyzing water quality and macro-invertebrates (insects, mollusks, crustaceans, and worms) can be barometers of stream health. Macro-invertebrates like stonefly larvae, mayfly larvae, caddis fly larvae, and certain snail species are indicators of unpolluted streams. Crayfish, dragonfly larvae, black fly larvae, crane fly larvae, and hellgrammites are organisms that tolerate a wide variety of conditions and endure some pollution. Macro-invertebrates like midge larvae and tubiflex worms, generally tolerate polluted conditions. So by collecting classifying, and establishing relative abundance of various species of macro-invertebrates, stream quality can be determined.

Threats to aquatic systems

Human activities are the main threats to aquatic systems. As the human population continues to increase, the increased demand for natural resources (particularly water) will affect aquatic systems. As previously discussed, human impacts include removal and transfer, pollution (point and non-point), erosion, siltation, and introduction of non-native species.

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